

CLAIMS

1. A quantum cascade laser, comprising
a semiconductor heterostructure providing a plurality of lasing modules connected in series, each lasing module comprising
a plurality of quantum well structures collectively generating at least an upper lasing state, a lower lasing state, and a relaxation state such that said upper and lower lasing states are separated by an energy corresponding to an optical frequency in a range of about 1 to about 10 Terahertz, and
wherein electrons populating said lower lasing state exhibit a non-radiative relaxation via resonant emission of LO-phonon into said relaxation state.
2. The quantum cascade laser of claim 1, wherein said non-radiative relaxation of the lower lasing state into the relaxation state at a selected operating temperature of said laser is faster than a corresponding relaxation rate of said upper lasing state into said lower lasing state, and wherein said resonant LO-phonon emission selectively depopulates the lower lasing state such that a ratio of a lifetime of said upper lasing state relative to lifetime of said lower lasing state is at least about 10.
3. The quantum cascade laser of claim 1, wherein said laser generates lasing radiation at an operating temperature above about 87 K.
4. The quantum cascade laser of claim 3, wherein the laser generates lasing radiation at an operating temperature above about 130 K.
5. The quantum cascade laser of claim 1, wherein the laser operates in a pulse mode.
6. The quantum cascade laser of claim 1, further comprising an electrical contact for applying a bias voltage across said semiconductor heterostructure.

7. The quantum cascade laser of claim 6, wherein said applied bias voltage causes a relaxation state of each lasing module to be in substantial resonance with an upper lasing state of an adjacent module to allow resonant tunneling of electrons therebetween.
8. The quantum cascade laser of claim 7, wherein electrons populating an upper lasing state of each lasing module exhibit a vertical optical transition into a lower lasing state of said module.
9. The quantum cascade laser of claim 1, wherein in each of said lasing modules, said relaxation state is characterized by a wavefunction exhibiting substantial amplitude in a first one of said quantum wells, said upper lasing state is characterized by a wavefunction substantially concentrated in quantum wells other than said first quantum well, and said lower lasing state exhibiting sufficient amplitude in said first quantum well so as to cause a substantial phonon coupling between said lower lasing state and said relaxation state.
10. The quantum cascade laser of claim 9, wherein for each of said lasing modules, both of said upper and said lower lasing states exhibit substantial amplitudes in at least one of said quantum wells so as to allow a vertical optical transition between said upper and lower lasing states.
11. The quantum cascade laser of claim 6, wherein in each of said modules, said quantum wells generate a fourth state in substantial resonance with said lower lasing state upon application of said bias voltage.
12. The quantum cascade laser of claim 11, wherein electrons populating said fourth state exhibit relaxation via resonant LO-phonon scattering into said relaxation state.
13. The quantum cascade laser of claim 1, further comprising an upper contact layer and a lower contact layer between which said semiconductor heterostructure is disposed.
14. The quantum cascade laser of claim 1, wherein said semiconductor heterostructure is formed as a stack of alternating GaAs and $\text{Al}_{0.15}\text{Ga}_{0.85}\text{As}$ layers.

15. The quantum cascade laser of claim 14, wherein said heterostructure has a thickness in a range of about 1 to about 10 microns.
16. The quantum cascade laser of claim 13, wherein said contact layers are formed of a heavily doped GaAs.
17. The quantum cascade laser of claim 16, wherein said contact layers are formed of GaAs having a doping level of about $3 \times 10^{18} \text{ cm}^{-3}$.
18. The quantum cascade laser of claim 1, further comprising a waveguide coupled to said semiconductor heterostructure for confining selected lasing modes of said laser.
19. The quantum cascade laser of claim 18, wherein said waveguide is formed of a metallic layer and a heavily doped semiconductor layer between which said semiconductor heterostructure is sandwiched.
20. The quantum cascade laser of claim 19, wherein said waveguide is formed of two metallic layers between which said semiconductor heterostructure is sandwiched.
21. The quantum cascade laser of claim 1, wherein a number of said lasing modules of said heterostructure range from about 100 to about 200.
22. The quantum cascade laser of claim 1, further comprising a semiconductor substrate on which said heterostructure is formed.
23. The quantum cascade laser of claim 22, wherein said substrate comprises a semi-insulating GaAs substrate.

24. A terahertz amplifier, comprising

an amplification structure formed as a semiconductor heterostructure including a plurality of amplification modules connected in series, each module comprising a plurality of quantum wells cooperatively generating an upper and lower amplification states and a relaxation state, said upper and lower states being separated in energy by a value corresponding to an optical frequency in a range of about 1 to about 10 Terahertz, said lower state being separated in energy from said relaxation state by a value substantially equal to an energy of at least one LO-phonon mode of said heterostructure such that electrons in said lower state exhibit relaxation into said relaxation state via resonant LO-phonon scattering,

an input port for coupling an input signal in a frequency range of about 1 to about 10 Terahertz into said amplification structure to generate an amplified signal, and

an output port for extracting said amplified signal from said amplification structure.

25. A quantum cascade laser, comprising

a semiconductor substrate,

a heterostructure formed on said semiconductor substrate, said heterostructure comprising a plurality of lasing modules connected in series, each of said modules comprising:

a plurality of quantum well structures collectively generating an upper lasing state, a lower lasing state, and a relaxation state, said upper and said lower lasing states having an energy separation corresponding to an optical frequency in a range of about 1 THz to about 10 THz,

wherein a vertical transition between the upper lasing state and the lower lasing state generates lasing radiation and resonant LO-phonon scattering of electrons from said lower lasing state into said relaxation state depopulates said lower lasing state to facilitate generation of a population inversion between the upper and the lower lasing states.

26. The quantum cascade laser of claim 25, wherein said LO-phonon scattering of electrons from said lower lasing state into said relaxation state exhibits a rate in a range of about 0.1 to about 0.6 picoseconds.